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Review

# Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway

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**Abstract:** Diffuse water pollution from agriculture (DWPA) is a major environmental issue worldwide causing eutrophication, human health problems, increased water treatment costs and reducing the recreational potential of water bodies. In addition to penalties and provision of incentives, policy efforts are increasingly focusing on raising land managers' awareness regarding diffuse pollution under the expectation that this would influence behaviours and thus increase uptake of best management practices that would, in turn, improve water quality. Given the multimillion financial investments in these awareness-focused approaches, a good understanding of the awareness–behavioural change–water quality pathway is critical to set the basis for assessing the real potential of these policy interventions. We systematically review the evidence across the full pathway drawing on published peer-reviewed papers from both the social and natural sciences, with a focus on Europe and North America. Results indicate that there is no one study that looks at the pathway in full, evidencing the paucity of research on the topic. For the limited studies that focus on the different components of the pathway, we find mixed evidence for the relationship between awareness and behaviour, and behavioural change and water quality. Furthermore, complexity within the pathway (e.g., through the study of factors mediating and moderating such relationships) has hardly been addressed by the literature. An in-depth understanding and analysis of this complexity—through an integrative model covering the entire pathway—could help in the design and implementation of effective policy strategies to encourage best land management practices and ultimately improve water quality.

**Keywords:** environmental knowledge; land management; pro-environmental behaviour; best management practice; water resource management; diffuse water pollution

## 1. Introduction

Diffuse water pollution from agriculture (DWPA) is a major environmental issue worldwide, causing eutrophication, human health problems, increased water treatment costs and reducing the recreational potential of water bodies [1–4]. In Europe for instance, diffuse agricultural pollution poses significant pressure on 38% of the region's water bodies [3]. As the pressure to increase food production globally augments, DWPA is likely to increase [3]. In their search for new strategies to tackle this problem, academics and policy makers have increasingly drawn their attention to understanding and influencing the behaviour of land managers over the past decade [5–7]. By addressing farmers' behaviours with respect to the adoption of best management practices (BMPs), it is expected that diffuse pollution at the catchment scale can be reduced [5,8,9].

Among other mechanisms (e.g., penalties, provision of incentives), one of the strategies towards changing land managers' behaviour has been the provision of advice and increasing awareness [5,10,11]. This has resulted in the development of novel awareness-focused approaches that represent a transition from top-down, punitive and narrow strategies to bottom-up, voluntary, collaborative and integrative ones [2,5,7,12–17]. This shift is as a result of the failure of earlier approaches to significantly tackle DPWA due to its complexities (e.g., DPWA has an emergent character, several causal factors with multiple stakeholders). These novel approaches are expected to enable policy-makers and catchment managers to tap into land managers' (and other stakeholders') knowledge regarding their farm environments and socio-ecological systems to understand the “why” and “how” to achieve better outcomes [13,14,17,18]. Notably, catchment-based approaches (CaBA)—also referred to as integrated catchment and watershed management programmes—are being used in Europe and North America to provide advice to farmers through various participatory means [12–14,17,19–23]. It is expected that such dialogical approaches increase land managers' awareness of diffuse pollution and mitigation measures, leading to changes in behaviour that would reflect in the adoption of best land management practices and ultimately in water quality improvement [13,14,17,18]. Awareness refers to land managers' consciousness of DPWA, mitigation measures, and/or associated consequences of (not) taking up such measures.

The cornerstone of these expectations is the assumption that a relatively straightforward link between awareness, behaviour and improvement in water quality can be established, but there is not yet a comprehensive review of the evidence to support this. The few existing reviews on this topic [8,24] have only covered individual links between awareness and behaviour and behavioural change and water quality, but not the pathway in full. For example, Baumgart-Getz et al. focused on factors that affect adoption of BMPs without looking at their impact on water quality [24]. On the other hand, Kay et al. focused on whether the implementation of BMPs led to an improvement in water quality, without consideration of whether and how awareness affect land managers' adoption of those practices [8]. Given that land managers' attitudes and behaviours are fundamental antecedents of environmental quality and change [25], we would argue that partial understanding of this pathway is going to fall short of providing the comprehensive understanding that is needed for effective policy designs. Considering the multimillion financial investments in these awareness-focused approaches [14], a good understanding of the awareness–behavioural change–water quality pathway is thus critical to set the basis for assessing the real potential of these policy interventions.

This improved understanding of the awareness–behavioural change–water quality pathway could help assess the effects of awareness-focused interventions as well as allow stakeholders to adjust policy strategies to help reverse increasing pollution of water bodies within local contexts [26]. We contribute to addressing this knowledge gap by systematically reviewing the evidence base of awareness–behavioural change–water quality pathway in full, with a regional focus (Europe and North America). The added value of this study therefore lies in its ability to uncover the full pathway and, unlike earlier reviews, cutting across the natural and social sciences. Specifically, the study seeks to answer the following questions: (1) What is the evidence base of the awareness–behaviour–water quality pathway? (2) Based on this evidence, can we establish which factors (referred to as mediators and moderators) affect or could affect the complex relationships within this pathway? and (3) Which aspects of the full pathway and which variables have received little or no attention and what does it say of our current ability to develop strategies to mitigate diffuse pollution from agriculture?

## 2. Methodology

We employed a systematic review method to evaluate and synthesize the evidence linking awareness, behavioural change and improvement in water quality [27,28]. This was done as a structured and iterative process in four phases. In Phase 1, data search and extraction included an online search for papers. This involved the application of clearly defined search terms to access publications from the following academic sources: Google Scholar, Web of Science, Scopus, the Applied

Social Sciences Index and Abstracts and Sociological Abstracts. Search terms covered the areas of environmental knowledge and awareness, behaviour, and water quality change as indicated in Table 1 (see Appendix A for an explanation on how the search items were applied). We restricted our search to documents published in English and within the last three decades (from 1987) because many contemporary diffuse pollution management policies and monitoring networks either commenced, became more consolidated or gained prominence around that time [8,9,21,29,30]. The final process in the literature search involved a snowball technique of manually tracing references from recent papers (e.g., [8,9,21,26]). This process yielded a total of 609 papers.

In Phase 2, references were filtered to remove duplicates, resulting in a total of 492 papers. In Phase 3 papers were screened to select those relevant to this study. To do this we read the titles, abstracts and the methodology section and applied the following inclusion criteria: reported the results of an empirical research, focused on the role of information or advice on uptake of diffuse pollution mitigation measures and/or water quality. After this stage, a substantial number of papers were excluded ( $n = 456$ ), resulting in 36 published papers. The 456 papers were excluded for either being a review paper (e.g., [5,8,10,19,24]), providing conceptual overview of integrated catchment management approaches (e.g., [15,18]) or not focused on any of the components of the pathway. Here, empirical research refers to evidence from scientific testing or observation as opposed to speculation, hypothetical modelling or anecdotal information. We selected empirical papers because the study aimed at providing the evidence base of the awareness–behaviour–water quality pathway thus, the need for ‘reliable information’ as opposed to speculations, anecdotal data, or papers providing conceptual overview.

Next, we retained only papers that were based on observation and from North America or Europe. Our reason for retaining only papers from these regions was to analyse papers from similar farming and policy settings, and which covered a region in which catchment-based approaches and awareness-oriented strategies are being clearly articulated and promoted [13,14,17,19,21,31]. Only 19 papers met all of the criteria outlined above and form the basis of this review (see Table A1 for an overview of these papers).

The fourth and final phase involved reading all of the 19 papers and extracting data relevant to the three research questions. A deductive approach was employed to analyse the evidence in relation to the three research questions: (1) what is the evidence base of the awareness–behaviour–water quality pathway? (2) Which factors affect or could affect this pathway? (3) Which aspects of the full pathway and which variables have received little or no attention? The approach offers the possibility to expound underlying connections between models and variables and the opportunity to take a broad view of research findings. The papers were evaluated critically for key results, with the aim of identifying the presence of an observed relationship between variables (which could be direct or indirect and/or positive, negative or mixed) or whether there was no evidence of a relationship.

Next, we checked whether authors reported psychosocial and biophysical variables (referred to as mediators and moderators (Mediators are variables through which an independent variable (e.g. awareness) transmits its effects onto a dependent variable (e.g. water quality) while moderators are those elements that contingently influence the statistical significance, direction and/or strength of the relationship between two or more other variables (e.g. awareness, behaviour and water quality).)) that affect or could affect the relationships under study. This is because the literature on environmental psychology, land management and environmental biogeochemistry have highlighted that some variables could affect the relationship between awareness and behaviour and behaviour and water quality. For instance, even when a farmer is aware of diffuse pollution mitigation measures, uptake of such measures is not guaranteed as this depends on e.g., farm type, scheme design, financial cost and time required to implement such mitigation measures [32–34]. Similarly, even when farmers implement the required mitigation measures, improvement in water quality is not guaranteed as this depends on e.g., land use type and intensity, pollutant type, crop uptake of nutrients, and for groundwater, this depends very much on the depth of the aquifer [21,26,35,36]. Investigating the interaction between these factors and the awareness–behaviour–water quality pathway is expected to enhance our understanding.

**Table 1.** Compilation of search terms.

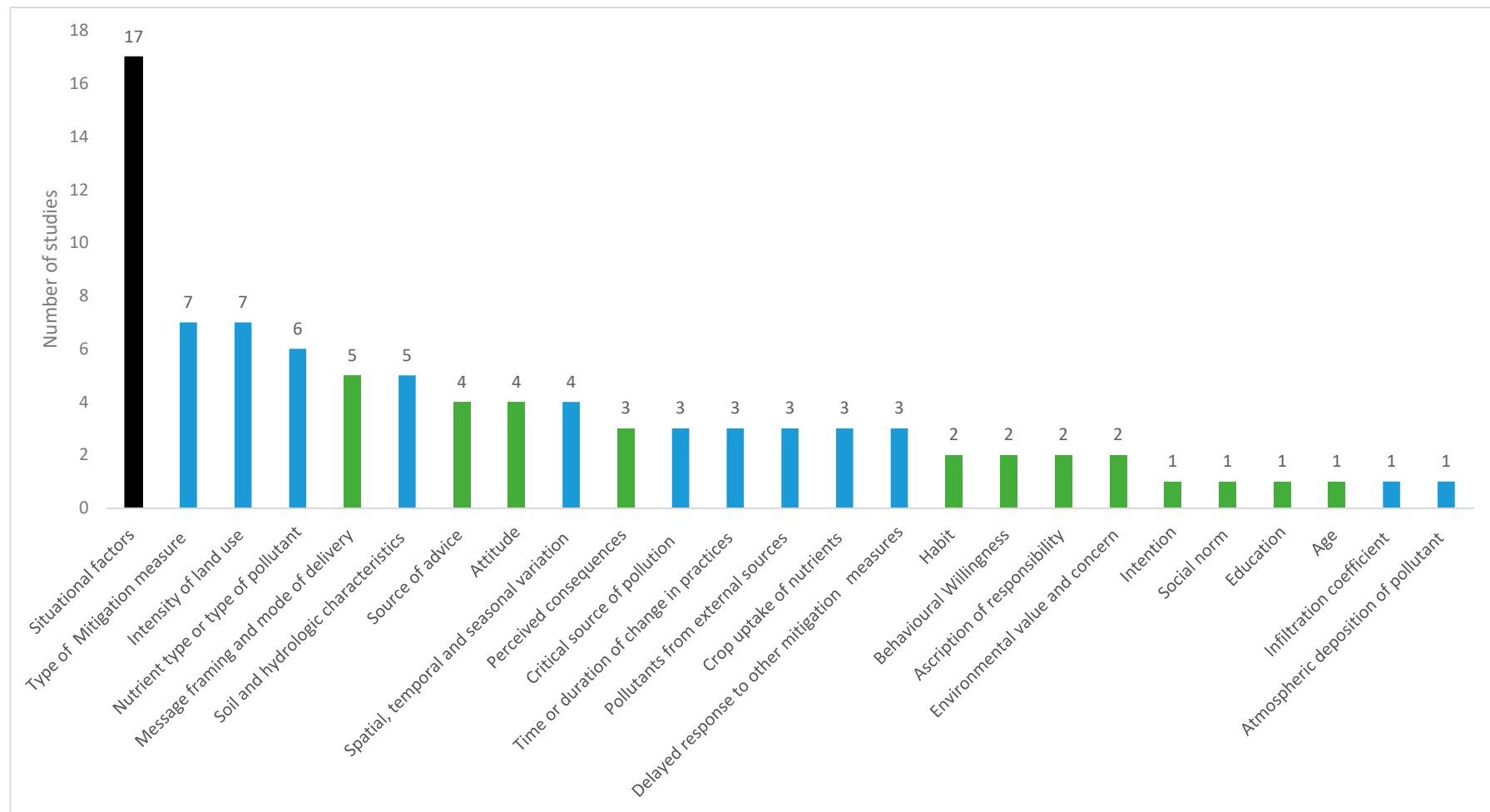
Group	Search Terms
1. Environmental knowledge and awareness	Advice; Agricultural Stewardship; Agrienvironmental Scheme; Appreciation; Consciousness; Awareness Campaign; Awareness; Environmental Concern; Environmental Education; Environmental Stewardship; Information; Intervention Programme; Knowledge; Recognition; Understanding
2. Behaviour	Act; Adoption; Apply; Carry Out; Compliance; Conform; Effect; Engage; Execute; Implementation; Perform; Practise; Uptake
3. Land management	Agricultural Change; Best Management Practice; Catchment Management; Catchment Sensitive Farming; Conservation; Diffuse Pollution Management; Diffuse Pollution Mitigation; Farm Management Practices; Farm Practices; Hydrologically Sensitive Area Measures; Land Quality Sustenance; Land Resource Management; Land Resource Use; Land Use Control; Land Use Pattern; River Basin Management; River Management; Soil Conservation; Soil Management; Sustainable Agriculture; Sustainable Farming Activities; Water Resource Management; Watershed Management
4. Water quality and agricultural pollutants	Agricultural River; Agricultural Runoff; Aquatic Ecosystem; Contamination Potential Index; Deposition Flux; Ecological Condition of Water; Ecological Status of Water; Groundwater Quality; Marine Eutrophication; Nitrate; Soil Water Retention; Nitrate; Nitrogen Deposition; Nitrogen Deposits; Nutrient Leakage; Nutrient Pollution; Pesticide concentration; Phosphate; Phosphorus Deposition; Phosphorus Exportation; Pollutant Concentration; Pollutant Load; Reduced Nutrient; River Water Chemistry; Riverine Loads; Stream Health; Stream Integrity; Stream Purification; Stream Water Quality; Surface Water Quality; Water Quality Assessment; Water Quality Improvement; Water Quality Index; Water Regulation Capacity; Watershed Hydrology; Sediment

### 3. Results and Discussion

#### 3.1. Overview of the Evidence

The 19 papers selected for the purpose of this study span both the social and natural sciences (Table A1). Nine papers covered the behavioural change–water quality link, nine covered the awareness–behaviour link, and one paper covered the awareness–water quality link. None of the papers explored the full awareness–behavioural change–water quality pathway.

Figure 1 and Table A2 provide information on potential mediators and moderators of the awareness–behavioural change–water quality pathway. From Figure 1, it is clear that some variables (e.g., situational factors) have received substantial attention in the academic literature, while others (e.g., moral norms) have received much less attention. Situational factors are extrinsic factors that facilitate or constrain farmers’ environmental behaviour and water quality responses. These may include institutional support (or lack of), farm size, farm type, farm tenure, income, cost of materials/compliance, ‘goodness of fit’ of schemes, flexibility of schemes, and variant of pollutant, among others. Of the 26 potential mediators and moderators, 14 of them are psychosocial factors (e.g., social norm, attitude, habit) mainly associated with awareness and behaviour. Eleven of these variables are biophysical factors (e.g., pollutant type, critical source of pollution) with direct implications for water quality, while the last variable (situational factors) affects both awareness and behaviour, and water quality.



**Figure 1.** Summary of variables affecting the awareness-behavioural change-water quality pathway. Note: Green = factors directly affecting awareness and behaviour; Blue = factors directly affecting water quality; Black = factor affecting awareness, behaviour and water quality.

### 3.2. Uncovering the Evidence-Base of the Awareness–Behaviour–Water Quality Pathway

In this section, we classify the evidence under the following components of the pathway: (i) awareness–behaviour change link; (ii) awareness–water quality link; (iii) behavioural change–water quality link; and (iv) the full awareness–behaviour–water quality pathway.

#### 3.2.1. Awareness–Behavioural Change Link

Almost all studies that reported on a direct relationship between awareness and behavioural change ( $n = 7$ ) indicate a positive effect with the exception of Barnes et al. and Macgregor and Warren who reported negative attitudes, lack of ascription of responsibility to self and unchanged behaviours despite the implementation of awareness campaigns and participation in schemes [33,34]. Two studies found a positive indirect effect through the mediating effect of agricultural stewardship [11,37]. That is, awareness affected participation in agricultural stewardship schemes and this in turn affected willingness and compliance with best land management practices.

Table 2 shows diffuse pollution mitigation measures and associated outcomes, as well as other variables that affect the awareness–behavioural change link. Results suggest that the relationship is influenced by a range of factors such as farm size, farm type, farm tenure, cost of materials/compliance, ‘goodness of fit’ of schemes, flexibility of schemes (see also Figure 1 and Table A2). Seven studies reported situational factors that affect this relationship [11,32], while social norm and intention were the least reported (only one study). Additionally, evidence shows that awareness itself may be dependent on sociodemographic characteristics (e.g., age, education level and gender), environmental values, concern and beliefs, thus, better access to information does not guarantee an increase awareness for the DWPA [38].

The idea that situational factors influence behaviours has been established in the literature, e.g., in Stern’s Attitude–Behaviour–Context model which postulates that the link between attitude and behaviour is dependent on situational factors [39]. Thus, where situational factors play a weak role, the direct link between attitude and behaviour is strong while this direct link weakens where the role of situational factors is strong. This is in line with the findings of some of the studies reviewed in this paper e.g., Macgregor and Warren, and Barnes et al. who found that attitudes and behaviours did not change despite awareness of the Nitrate Vulnerable Zones (NVZ) scheme (attributable to the inflexible nature of schemes, time and financial cost of compliance) [33,34]. The inflexible nature of schemes makes it often harder for farmers to respond to changes in markets thus even if advice is good, the scheme may not be flexible enough to allow uptake of BMPs—highlighting the crucial role of situational factors (e.g., scheme content and design). Overlooking these factors weakens the analysis and understanding of the awareness–behaviour link. This in turn limits our ability to design policies that can be adapted to various contexts or situations.

Although other potential moderators (e.g., source of advice, message framing and means of delivery) have not been widely studied and reported in the diffuse pollution management literature, they play a key role and need to be considered in policy designs. For instance, the limited research in this field has indicated that the source of information (i.e., the institution that is sending the information and/or the farm advisor) is a crucial factor determining whether land managers take up best land management measures or not, especially where the message is well-placed, consistent and well framed [40–42]. Additionally, uptake across catchment might be influenced by social norms, that is, farmers are more likely to take up BMPs where their neighbours adopt such practices and the practices become embedded in their norms [43,44].



**Table 2.** Effects of awareness on behaviour via uptake of diffuse pollution mitigation measures.

Link	Diffuse Pollution Mitigation Measure(s)	Results	Other Influential Factors	Method	Number of Respondents	Reference
Direct relationship	Advice on general conservation/biodiversity management	59% adopted scheme measures.	Scheme design or package, farm system and income sources.	Survey and statistical test	144	[32]
	General BMPs for farms and diffuse pollution advice	Awareness affects adoption ( $p \leq 0.05$ ).	Belief, farm tenancy, access to equipment, farm size, and trust in source of advice.	Surveys, open interviews, focus groups and statistical analysis	145 1320 30 *	[45] [46] [23]
	Nutrient management, filter strips, and streambank fencing	Those who were aware of nutrient management regulations were 28% more likely to adopt nutrient management as a BMP, and was found to increase filter strip adoption by 24%.	Business ownership, years anticipated to remain in business, education, cost/benefit.	Survey and statistical test	150	[22]
	NVZ-related advice	Despite awareness of the NVZ regulations, farmer attitudes indicate a somewhat negative view towards the perceived environmental benefits, water management and behaviours have not changed.	Ascription of responsibility, attitudes and inflexible nature of regulations	Survey, workshops, interviews and statistical analysis	184 30 *	[33,34]
Indirect relationship	Diffuse pollution measures to protect water quality	Awareness influenced willingness ( $p \leq 0.05$ ) to adopt as well as adoption/compliance ( $p \leq 0.1$ ) indirectly through the mediating effect of agricultural stewardship. 46.2% complied with regulations.	Farm type and location.	Survey and statistical test	647 1564	[11,37]

For number of respondents, \* indicates number for qualitative interviews; all others are surveys. Number of respondents follow a respective order where there are two or more references.



### 3.2.2. Awareness and Water Quality Link

This was the least studied link in the awareness–behaviour–water quality pathway, with only one study found in the literature. Kreuger and Nilsson found that Swedish aquatic ecosystems underwent remarkable (more than 90%) reductions in concentrations of pesticides in catchments where farmers received catchment specific information regarding best pesticide management practices [47]. Based on expert judgement and qualitative reasoning, they attribute this to an improvement in land management owing to awareness of BMPs regarding handling of spraying equipment and application procedures. However a clear link between both awareness and water quality is still missing. Further research is thus required to exploring how awareness translates into water quality improvements, what's the role of other influential factors such as farmer attitude, behaviours, and biogeochemical changes and ultimately what's the effectiveness of awareness centred approaches.

### 3.2.3. Behavioural Change and Water Quality Nexus

The nine papers reviewed found contrasting evidence for a relationship between uptake of mitigation measures and improvements in water quality (Table 3). Four papers found a positive effect, and five reported mixed results i.e., positive effect in some (sub) catchments, negative results in others and no changes in some others. Eight papers reported variation in results for different pollutants while five (of those eight papers) reported variation across (sub) catchments. For instance, Kay et al. reported a decline in nitrate concentrations in 7 of the 10 sub-catchments studied and that there was no decrease in phosphorus in any of the sub-catchments [9]. They attributed this variation to a number of potential factors such as time lag and the fact that these pollutants derive from other sources than just agriculture. This means that even when farmers take up mitigation measures, the impact on pollutant concentration and/or loads (and by extension, water quality) depends very much on the type of pollutant. For example, in the case of phosphorus, research has shown that the impact on concentrations may take longer to be realised due to the build-up of phosphorus in soils and river sediments—raising concerns about time lags [13,14,48–50]. In catchments dominated by groundwater, nitrate usually moves slowly through the aquifer. Thus it can take several decades to reach rivers and so the impacts of land management actions (e.g., reduced fertiliser application) may not be evident for many years [49]. As Kay et al. noted, the decline in nitrate concentration observed in some sub catchments could be due to delayed impacts of the implementation of NVZs [9]. Such temporal and spatial mismatches may affect a direct relationship being observed in the short-term between behavioural change and improvements in water quality.

We also found that the variation in results across (sub) catchments could also be attributed to different levels of uptake by land managers across catchments and the focus of mitigation measures (e.g., [8,9,51]) which may be difficult to determine at the broader catchment scale. That is, farmers in some (sub) catchments may not implement the recommended measures and the measures implemented may vary in terms of focus: some farmers may adopt mitigation measures that are more focused on reducing nitrate leaching to water bodies as opposed to mitigation measures that are more focused on phosphorus. For instance, if farmers implement manure focused mitigation measures, this could result in little or no reduction in other pollutants e.g., sediments [51]. However, if the mitigation measure focuses on reducing soil erosion, it is more likely that significant reduction in sediments will be realised [51]. This complex interaction between type of mitigation measures and uptake of measures needs to be more critically considered at the catchment scale to assess effectiveness of mitigation measures.

Again, biophysical factors such as the geological and climatic characteristics of the land affect the impact of behavioural changes on water quality [21,26,52,53]. For instance, if farmers in two different catchments take up the same mitigation measures on their farms, improvement in water quality is likely to be lower in a catchment with high runoff. Ryberg et al. use structural equation modelling to show how these factors including climate variability and anthropogenic factors interact in a complex manner to determine phosphorus loads—a key measure of water quality—in the Chesapeake

Bay watershed [54]. They found that while purposeful management practices help in decreasing phosphorus loading in the watershed, the effects are counterbalanced by increasing runoff attributed to natural climate variability.

Other factors that may play a role include differences in land use, crop uptake of nutrients, and for groundwater, this depends very much on the depth of the aquifer [21,26,35,36]. Additionally, the intensity of land use may affect pollutant loads in water resources although reduced production and/or productivity levels do not always result in significant reduction of agricultural pollutants in water bodies [55]. Moreover, some land units may be critical sources of diffuse pollution than others [9,26]. This is related to hydrologically sensitive areas (i.e., the portion of land within the catchment which contributes actively to runoff) and critical source area (that is, the portion of land within the catchment where large amounts of pollutants are generated) that may serve as explanatory variables to water quality responses [26]. For instance, Thompson et al. found that arable soils produced more suspended sediment than grassland and woodland in some catchments [56].

**Table 3.** Effects of uptake of mitigation measures on water quality.

Pollutant	Mitigation Measure(s)	Results	Other Influential Factors	Reference
Nitrate	Implementation of the Code of Good Agricultural Practice and measures in Nitrate Vulnerable Zones (NVZ).	Nitrate concentrations decreased significantly in 7 out of 10 sub catchments. The median nitrate concentration reduced from 3.7 mg N L <sup>-1</sup> before implementation to 2.7 mg N L <sup>-1</sup> after implementation (study conducted between 2006 and 2009).	Time lag i.e., delayed benefits of NVZ actions (as this started in 2002).	[9]
	Reduction in the percentages of arable crops, lower N fertiliser use in arable farming, greater extent of cover cropping, grassland with little or no N fertilisation.	Nitrate content reduced by 3.2 mg L <sup>-1</sup> , with up to −4.4 mg L <sup>-1</sup> observed in some areas. Mean reduction in N leaching of 29% (16 kg N ha <sup>-1</sup> year <sup>-1</sup> ) for the arable land in the Fehrltorf catchment.	Soil and hydrological characteristics, type of mitigation measure and critical source, scale of analysis.	[57]
	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	No significant changes in concentration was observed except for an increase in one river (the River Ra'pu). For ground water, recent (since 2003) results indicate a slight increase in nitrate content in those areas with more intensive agriculture.	Land use intensity, soil and hydrological characteristics, and how long measure was implemented.	[21]
	Use of buffer strips (For a more detailed review of nutrient efficacies of buffer zones, see Kay et al. (2009).)	No statistically significant differences were observed (at P > 0.05) between buffer strip (BS) and no buffer strip (no-BS). Nutrient removal efficiency: 9% decrease–217% increase	Spatial and seasonal variation, soil and hydrological characteristics.	[58]
	Buffer strips (BS) A fertilization rate reduction by 15% and 30%BS, fertilizer reduction, Pasture land increase and other BMPs.	A reduction of 3.9–9.3% in nitrate load depending on width of BS 15.1% and 25% reduction respectively in nitrate loads4.7–38.2% reduction in nitrate loads; results varied across seasons.	Land use intensity and how long measure was implemented.	[59]
	Reduce fertilizer application	Land with nitrate concentrations exceeding 50 mg L <sup>-1</sup> observed 13–33% reduction but results vary across different variants of N. Nitrate leaching decreased by 0.08 kg ha <sup>-1</sup> year <sup>-1</sup> when the net N loading of the soil decreased by 1 kg ha <sup>-1</sup> year <sup>-1</sup> , but results differed across soil type, land use and hydrology. Land with nitrate concentrations exceeding 100 mg L <sup>-1</sup> decreased from 1%–17% depending on the variant of N.	Pollutant type, type of mitigation measure, spatial and seasonal variation, land use intensity, how long measure was implemented, external sources, crop uptake of nutrients.	[60]
Total N	NVZ regulations	29% of NVZs showed a significant improvement but 31% showed a significant worsening. The average improvement relative to a control due to NVZ designation was 0.02 ± 0.08 mg N L <sup>-1</sup> year <sup>-1</sup> .	Type of mitigation measure, soil and hydrological characteristics, land use intensity.	[61]
	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	A statistically significant decreasing trend in TN was observed in the River Po–Itsamaa	Pollutant type, type of mitigation measure, critical source, spatial and seasonal variation, soil and hydrological characteristics and external sources.	[21]
	Reduced autumn ploughed area between 7% and 17%, introduction of catch crop and constructed wetlands.	Non-statistically significant downward trend observed ( <i>p</i> -value ≥ 0.05), though some catchments show a decline or an increase in absolute values.	Differences in crop type, land use intensity, fertilizer application and delay in uptake of measures in some catchments. Intensity of advisory services and financial support varied.	[62]
	Use of buffer strips	Reducing total nitrogen losses from 17.3 to 4.5 kg ha <sup>-1</sup> in terms of mass balance. Nutrient removal efficiency: 10% decrease–217% increase	Spatial and seasonal variation, soil and hydrological characteristics.	[58]
	Tramline management	74–98% reduction in what total N	Pollutant type, type of mitigation measure, spatial, temporal and seasonal variation.	[63]

Table 3. Cont.

Pollutant	Mitigation Measure(s)	Results	Other Influential Factors	Reference
Total P	Placement of in-field manure heaps, soil and manure nutrient content analysis, leaving buffer zones next to water courses when spreading manure and reseeded grassland, installing stream fencing to exclude livestock.	Remained relatively static except for 1 monitoring site where a reduction was observed, even with that, the <i>p</i> -value of regression analysis was non-significant.	Probably due to some farmers not engaging and others implementing particular measures only.	[9]
	Reduction in the percentages of arable crops, Lower N fertiliser use in arable farming, greater extent of cover cropping, Grassland with little or no N fertilisation.	The P pollution of Swiss surface waters from farm systems reduced by between 10% and a maximum of 30%.	Soil and hydrological characteristics, type of mitigation measure and critical source.	[57]
	Reduced autumn ploughed area between 7% and 17%., introduction of catch crop and constructed wetlands.	Nonstatistically significant downward trend observed ( <i>p</i> -value $\geq 0.05$ ) though some catchments show a decline in absolute values.	Differences in crop type, type of mitigation measure, intensity of land use, soil and hydrologic characteristics, how long measure was implemented, intensity of advisory services, level of financial support.	[62]
	Use of buffer strips	27% reduction–41% increase in total P	Spatial and seasonal variation, soil and hydrological characteristics.	[58]
	Tramline management	72–99% reduction in total P	Type of mitigation measure, spatial, temporal and seasonal variation.	[63]
	Reduce fertilizer application	Reduction in P leaching to surface waters was much less than 0.1 kg ha <sup>−1</sup> when the net P loading of the soil diminished by 1 kg ha <sup>−1</sup> (mainly because P is strongly retained by the soil).	Type of mitigation measure, spatial and seasonal variation, land use intensity, how long measure was implemented, external sources, crop uptake of nutrients.	[60]
Dissolved P	Placement of in-field manure heaps, soil and manure nutrient content analysis, leaving buffer zones next to water courses when spreading manure and reseeded grassland, installing stream fencing to exclude livestock	Remained relatively static except for 1 monitoring site where a reduction was observed, with the <i>p</i> -value of regression analysis being significant.	Possibility of external sources of pollutants e.g., Boron.	[9]
	Implementation of the Code of Good Agricultural Practice, spatial and temporal restrictions for use of fertilisers, buffer strips along the water courses, protection zones around the wells, etc.	No significant trends in P concentrations in agricultural rivers since the 1990s except for an increase in the River Ra'pu.	Farm type, land use intensity and external sources of pollutants.	[21]
	Use of buffer strips	No significant differences in total P concentrations between BS and no-BS but the median reduction (almost 22%) became significant ( <i>P</i> < 0.05). Nutrient removal efficiency: 17% decrease–475% increase	Spatial and seasonal variation, soil and hydrological characteristics.	[58]
Sediment	Reduced autumn ploughed area between 7% and 17%., introduction of catch crop and constructed wetlands.	Non-statistically significant downward trend for some catchments, but one catchment shows a statistically significant upward trend ( <i>p</i> -value $\leq 0.05$ )	Differences in crop type, land use intensity, fertilizer application and delay in uptake of measures in some catchments. Variation in intensity of advisory services and financial support.	[62]
	Use of buffer strips	78% reduction in sediment losses	Spatial and seasonal variation, soil and hydrological characteristics.	[58]
	Tramline management	75–99% reduction in sediment losses	Type of mitigation measure, spatial, temporal and seasonal variation.	[63]

### 3.2.4. Awareness–Behaviour–Water Quality Pathway

We did not find any primary study in the academic literature that investigates the full awareness–behaviour–water quality pathway, although researchers often tried to link these variables using correlation analysis, qualitative inferences and/or expert judgement (e.g., [9]). As such, there is currently a lack of evidence on the hypothesis that land managers who are aware of diffuse pollution and mitigation measures are more likely to take up these measures and this, in turn, may result in improvements in water quality.

Additionally, none of the studies reviewed in this study considered the joint effect of psychosocial and biophysical factors on land management and water quality. While existing studies examined the factors that can potentially affect awareness and adoption of diffuse pollution mitigation measures, the mechanisms and the conditions under which this happens (i.e., the relevant mediators and moderators) and whether some of these factors are confounding variables remain understudied. However, when these variables are considered in first generation statistical techniques (e.g., correlations, multiple regressions), they are found to have an influence on awareness and/or adoption of mitigation measures (e.g., [64–66]). These findings point to the need for developing more sophisticated analysis that takes into account the complex nature of catchments, pro-environmental behaviour and diffuse agricultural water pollution [11,15,25]. Knowledge of the mechanisms and interactions between awareness and these variables can help to design more targeted and effective land use policies [10,54].

We now turn to discuss potential limitations of our study. For instance, although the strategy adopted in the data gathering process, a multi-pronged method enhances precision and recall rates [67], there is a danger that a few studies are missed if they do not contain the search terms in their titles, keywords and abstracts. That is, there could be work on the impact of specific measures (e.g., cover cropping) on specific pollutants other than the ones selected but they will not be reported as ‘water quality’. We attempt to mitigate this limitation by using the snowball technique where key references are traced as well as randomly reading additional papers. Nonetheless, we admit there is the possibility that we missed a few key papers.

Like all narrative and vote counting reviews, this research was unable to determine the overall magnitude (and statistical significance) of the relationship between the constructs as well as the cause of discrepancy in results of the different primary studies [68]. The method allows for the identification of potential factors (e.g., methods) responsible for the discrepancy in results of the various primary studies, however does not enable the determination or confirmation of statistical significance. Therefore, while we encourage more primary research on the topic, it is important that future reviews employ meta-analytic techniques to determine overall magnitude of the relationship between awareness, behavioural change and water quality as well as the bases of variation in outcomes reported across studies [68].

## 4. Concluding Remarks

Diffuse water pollution from agriculture (DWPA) is a major and persistent environmental issue worldwide causing multiple problems. Recent policies introduced to improve water quality have focused on raising land managers’ awareness regarding diffuse pollution, under the expectation that this would influence behaviours and thus increase uptake of best management practices. As stakeholders commit financial resources to awareness-focused approaches, it is important that a good understanding of the awareness–behavioural change–water quality pathway is developed to assess the effects of these policy interventions. In this study, we systematically review, for the first time, the evidence across the full pathway drawing on published peer-reviewed papers from both the social and natural sciences.

Results indicate that there is no study that looks at the pathway in full, showing the paucity of research on the topic. For the existing studies that focused on the different components of the pathway, we find mixed evidence for the relationship between awareness and behaviour, and behavioural change and water quality; some studies reported negative relationships, others found positive relationships,

yet other studies reported that no impact on behaviour and water quality was found despite the implementation of awareness-focused interventions. Furthermore, complexity within the pathway has hardly been addressed by the literature. Complexity and variability of diffuse water pollution, catchments and pro-environmental behaviour challenge our ability to design ‘tailored’ diffuse water pollution reduction measures. However, from a research perspective, a better understanding of the factors that mediate or moderate the relationships between the various components of the pathway might enable us to disentangle the mechanisms through which these relationships operate as well as the conditions under which they occur. Such a more profound understanding would offer an opportunity to design and implement more context-specific, and possibly more effective policies to influence uptake of BMPs and ultimately improve water quality. This could be facilitated through the development of an integrative model, in which researchers treat behavioural change as a key mediator in the relationship between awareness and water quality, with other situational, biophysical and psychosocial factors acting as moderators of these relationships across the awareness–behaviour–water quality pathway.

From a policy perspective, policymakers need to incorporate the relevant factors outlined in the full pathway in their strategies to influence uptake of mitigation measures. The outcomes and impacts of such strategies on behaviour and water quality could then be evaluated using the integrative models developed from research. While the implementation of such integrative models could be challenging, their application could offer very useful understandings of the role of DWPA policies.

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## Appendix A. Application of search terms

### Awareness–behaviour link:

Search terms applied covered terms in group 1, 2 and 3: e.g.,

Knowledge **PLUS** implement\* **PLUS** farm practice\* (*using \* to capture the fullness of the topic, and “AND” to enhance relevance of returned outputs*).

### Awareness–water quality link:

Search terms applied covered terms in group 1, and 4: e.g.,

Knowledge **PLUS** water quality improvement\* (*using \* to capture the fullness of the topic, and “AND” and “OR” enhance relevance of returned outputs and, also capture papers that included knowledge and any of the environmental outcomes under consideration*).

### Behaviour–water quality link:

Search terms applied covered terms in group 2, 3 and 4: e.g.,

Adopt\* **PLUS** diffuse pollution mitigation measure\* **PLUS** water quality improvement (*using \* to capture the fullness of the topic, and “AND” and “OR” enhance relevance of returned outputs and, also capture papers that included knowledge and any of the environmental outcomes under consideration*)

**Finally, an overall search was run to cover all groups (1–4).** Combinations of all these was done systematically for all search terms under each of the groups. The final process in literature search involved a snowball technique of manually tracing references from key papers such as [8,9,26].

## Appendix B

Table A1. List of Final Papers Used for the Evidence Review.

Study	Title	Location	Journal
[9]	The effectiveness of agricultural stewardship for improving water quality at the catchment scale: Experiences from an NVZ and ECSFDI watershed	United Kingdom	Journal of Hydrology **
[32]	Environmental Stewardship in UK Agriculture: A Comparison of the Environmentally Sensitive Area Programme and the Countryside Stewardship Scheme in South East England	United Kingdom	Geoforum *
[33]	Farmer perspectives and practices regarding water pollution control programmes in Scotland	United Kingdom	Agricultural Water Management *
[62]	Monitoring catchment scale agricultural pollution in Norway: policy instruments, implementation of mitigation methods and trends in nutrient and sediment losses	Norway	Environmental Science & Policy ***
[58]	Effectiveness of buffer strips in removing pollutants in runoff from a cultivated field in North-East Italy	Italy	Agriculture, Ecosystems & Environment ***
[63]	Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures	United Kingdom	Agricultural Systems **
[23]	Generating applicable environmental knowledge among farmers: experiences from two regions in Poland	Poland	Agroecology and Sustainable Food Systems *
[37]	Toward a theory of farmer conservation attitudes: Dual interests and willingness to take action to protect water quality	United States	Journal of Environmental Psychology *
[59]	Assessing the impacts of Best Management Practices on nitrate pollution in an agricultural dominated lowland catchment considering environmental protection versus economic development	Germany	Journal of Environmental Management ***
[22]	Awareness and pro-active adoption of surface water BMPs	United States	Journal of Environmental Management ***
[57]	Environmental cross-compliance mitigates nitrogen and phosphorus pollution from Swiss agriculture	Switzerland	European Journal of Agronomy **
[21]	Monitoring of diffuse pollution from agriculture to support implementation of the WFD and the Nitrate Directive in Estonia	Estonia	Environmental Science & Policy ***
[47]	Catchment scale risk-mitigation experiences- key issues for reducing pesticide transport to surface waters	Sweden	British Crop Protection Council Symposium Proceedings **
[61]	The effectiveness of nitrate vulnerable zones for limiting surface water nitrate concentrations	United Kingdom	Journal of Hydrology **
[60]	Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands	Netherlands	Journal of Hydrology **
[46]	Identifying and understanding factors influencing the uptake of new technologies on dairy farms in SW England using the theory of reasoned action	United Kingdom	Agricultural Systems **
[46]	Measuring and understanding agricultural producers' adoption of nutrient best management practices	United States	Journal of Soil and Water Conservation **
[34]	Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: The view from the farm	United Kingdom	Agriculture, ecosystems & environment ***
[11]	Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: a conditional process modelling	United Kingdom	Land Use Policy ***

Notes: \* = Social science focused; \*\* = Natural Science focused; \*\*\* = Cuts across the social and natural sciences.



**Table A2.** Summary of variables affecting the awareness–behavioural change–water quality pathway.

Categories: Focus of Study	Study	Source of Advice (a)	Message Framing and Mode of Delivery (a)	Beliefs (a)	Attitude (a)	Habit (a)	Intention (a)	Behavioural Willingness (a)	Social Norm (a)	Perceived Consequences (a)	Ascription of Responsibility (a)	Education (a)	Age (a)	Situational Factors (c)	Environmental Value and Concern (a)	Nutrient Type or Type of Pollutant (b)	Type of Mitigation Measure (b)	Critical Source of Pollution (b)	Spatial, Temporal and Seasonal Variation (b)	Intensity of Land Use (b)	Soil and Hydrologic Characteristics (b)	Time or Duration of Change in Practices (b)	Pollutants from External Sources (b)	Crop Uptake of Nutrients (b)	Infiltration Coefficient (b)	Delayed Response to other Mitigation (b) Measures	Atmospheric Deposition of Pollutant (b)
Awareness and behavioural change link	[32]				x				x	x			x		x												
	[46]																										
	[37]			x				x						x													
	[22]											x		x													
	[46]	x												x													
	[33]		x	x	x	x								x													
	[34]			x	x	x				x	x			x													
	[23]	x	x	x	x									x													
Awareness and water quality link	[11]													x	x												
	[47]	x	x					x									x										
Behavioural change and water quality link	[58]													x					x						x		
	[63]													x		x	x		x								
	[59]													x						x							
	[60]													x		x	x	x	x	x		x	x	x			
	[62]													x			x			x	x						
	[9]													x		x		x	x	x			x			x	
	[21]													x						x	x						
	[63]		x											x		x	x			x	x	x		x		x	
Number of studies reporting variable	[57]													x		x	x			x							x
		4	5	5	4	2	1	2	1	3	2	1	1	17	2	6	7	3	4	7	5	3	3	3	1	3	1

Notes: x = reported in the study; Letters in parenthesis: a = factors directly affecting awareness and behaviour; b = factors directly affecting water quality; c = factor affecting awareness, behaviour and water quality.

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